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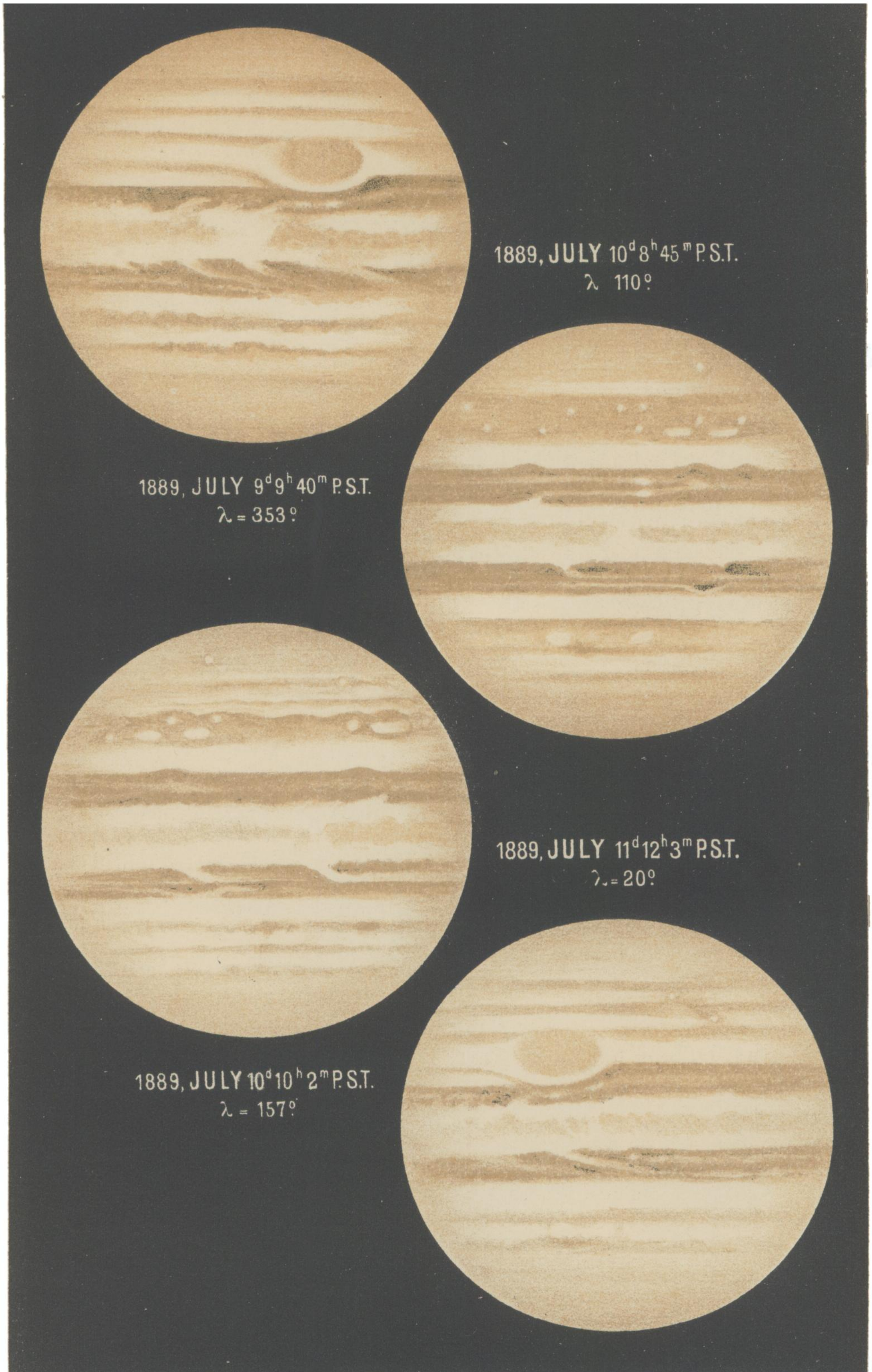

Lith. Anst. u. Steindr. v. C. L. Keller. Berlin, S.

Jupiter im Jahre 1889.

Am 36-Zöller der Licksternwarte

gezeichnet von J. Keeler.

PUBLICATIONS

OF THE

Astronomical Society of the Pacific.

VOL. II. SAN FRANCISCO, CALIFORNIA, NOVEMBER 29, 1890. NO. 11.

ON THE MOTIONS OF THE PLANETARY NEBULÆ IN THE LINE OF SIGHT.

BY JAMES E. KEELER.

The following paper contains a preliminary account of researches on the spectra of the planetary nebulæ, and a statement of the results of measurements which show that some of the nebulæ, which have hitherto been supposed to be at rest relatively to the solar system, have a considerable motion in the line of sight.

The first spectroscopic observations of nebulæ made at the Lick Observatory were undertaken at the request of Dr. HUGGINS, who asked that the position of the brightest line in the spectrum of the *Orion* nebula should be determined with reference to the lower edge of the magnesium fluting which falls at nearly the same place, with the aid of the thirty-six-inch equatorial, and also that the character of the nebular lines should be examined. The origin of the nebular lines was at that time the subject of considerable discussion.

Although the nebula was too far past the meridian when Dr. HUGGINS' letter was received to allow of the satisfactory employment of the comparison apparatus for determining positions, an examination of the lines was made, under sufficiently favorable circumstances, with a number of different spectroscopes. The largest of these, with which were made the observations hereafter to be described, has a collimator of twenty inches focus and an observing telescope of about half that length. A single 60° prism was first employed, then a compound prism of about three and one-half times the dispersion of the latter, and finally a ROWLAND grating of 14,438 lines to the inch. With all these different degrees of dispersion, and also with the other spectroscopes employed, the nebular lines appeared to be perfect monochromatic images of the slit, widening when the slit was widened, and narrowing to exces-

sively fine, sharp lines when it was closed up. The brightest line showed no tendency to assume the aspect of a "remnant of fluting" under any circumstances of observation, but had always the appearance characteristic of light emitted by a gas at low temperature and pressure.

A few measures which were made of the position of the brightest line, under extremely disadvantageous circumstances, were unsatisfactory, and probably erroneous, and they are not given in the accompanying list, but will be repeated at the first opportunity. This part of the observations being undecisive, I therefore, at Dr. HUGGINS' request, examined the spectra of the nebulæ *G. C. 4234* (Σ 5) and *G. C. 4373*. In both of these nebulæ the brightest line fell well above the lower edge of the MgO fluting, with which it could not be made to coincide by any mal-adjustment of the comparison-spark; but while thus amply confirming the opinion of Dr. HUGGINS in regard to the non-coincidence of the nebular line and the terminal line of the magnesium fluting, the difference in position of the brightest line in the two nebulæ was so considerable, and so much greater than the errors of observation, as to show conclusively that one or both of the nebulæ had a considerable motion in the line of sight. I therefore undertook the determination of the position of the bright lines in the spectra of all the nebulæ within the range of the apparatus, with the greatest attainable degree of accuracy. Some of these measures have already been completed, and the results are given in the present paper.

The positions of the three brightest lines in the spectra of a number of planetary nebulæ were determined in 1868 by Lieutenant HERSCHEL,* but with apparatus so deficient in optical power that the whole range of the small displacements I have observed was covered by the errors of observation. Similar measures were made by BREDICHIN † in 1875, but the accuracy attained was not much greater than that of the observations just quoted. Professor BREDICHIN concluded, however, that the lines in the different nebulæ are identical in origin. VOGEL,‡ in 1871, determined the position of the brightest line in the spectra of six nebulæ (including the nebula of *Orion*) with a degree of precision much greater than that of previous observations, but still not sufficient

* *Royal Soc. Proc.*, vol. 16, p. 451.

† Spectre des Nébuleuses. *Annales de l'Observatoire de Moscou*, ii (2me liv.) p. 60.

‡ *Bothkamp Beobachtungen*, Leipzig, 1872.

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for the purpose now under consideration. In a paper published in 1874, HUGGINS* gives the results of an examination of seven gaseous nebulæ, including the nebula of *Orion*, and states that in no instance was any change of relative position of the nebular line and the lead line (used in comparison) detected. From observations made at Greenwich in 1884, MAUNDER concluded that the nebula of *Orion* has little, if any, motion in the line of sight.

As the statement of HUGGINS in the paper just referred to cannot be reconciled with my own observations, I at first attributed the differences in position of the nebular lines to constant errors affecting my own apparatus; but the most varied tests failed to reveal the existence of such errors, and only convinced me of the reliability of the results. As the displacements are small, and the nebular lines faint, it is probable that the observations are beyond the range of all but the most powerful apparatus.

The conclusion that the nebulæ have no motion relatively to the solar system would appear on *a priori* grounds to be improbable. The stars, which in general are found to have considerable motions in space, are, according to modern views, evolved from pre-existing nebulæ by a process of contraction or condensation, and any motion of translation possessed by the star must have been inherent in the original nebulæ, since in no way could such a motion have been acquired by any internal action during the process of condensation. The *absence* of motion in the nebulæ would, in fact, if proved by observation, be a remarkable circumstance which would need to be explained.

The large star spectroscope which was used in the observations at the Lick Observatory is one of the finest specimens of BRASHEAR'S work. A complete description of the instrument will not be given here, but certain features, which are directly concerned in the measurements, require notice. The collimator is of twenty inches focal length, the observing telescope ten and one-half inches, and both objectives are of Jena glass. The effective aperture of the collimator, when used on the thirty-six-inch equatorial, is 1.06 inches, and the actual aperture was reduced to this by a stop, in order to limit the emergent beam from the comparison-spark. Two eye-pieces were used, one giving a power of 7.3 and the other of 13.3 diameters. The higher power was generally found to be the more satisfactory, except on unusually faint nebulæ. The micrometer has a fine

* *Royal Soc. Proc.*, vol. 22, p. 253.

wire, a coarse wire, and a pointer. The value of one revolution is 3′ 10″.8.

Light from the comparison-spark or tube is thrown into the collimator by a totally-reflecting prism, and the arrangement which I have devised for the Lick Observatory spectroscope is intended to be free from the objections which have been made to the usual construction in which the comparison-prism is employed. An image of the spark, intentionally somewhat out of focus, is formed on the slit by a lens having a greater angular aperture than the collimator objective. The comparison-prism can be moved smoothly along the slit in the direction of the spark by turning a milled head within reach of the observer. The slit is variable in length as well as in breadth, two small slides moving lengthwise equally from the center, and operated by a knob, being the means by which the change is effected. A diagonal eye-piece, which is slightly withdrawn when the adjustment of the spectroscope is complete, is used for viewing the slit from behind.

When an object, such as a planetary nebula, is observed, it is first centered in the slit by the slow motions of the telescope, with the aid of the diagonal eye-piece just mentioned. The slit is then shortened until its length is just equal to the diameter of the nebula, and its width is reduced to suit the requirements of observation. The slit is then evidently completely filled with light from the nebula. After its image has been bisected with the micrometer wire, the comparison-prism is moved into place, and the image of the nebula is replaced by the image of the comparison-spark. It is evident that the rays of light from both sources enter the same part of the slit, traverse the same path in the spectroscope, and fall upon the same part of the micrometer wire. If desired, the two spectra can be compared directly, the comparison-prism being then moved so as not to completely cover the open part of the slit.

In observing the nebulæ, a ROWLAND grating of 14,438 lines to the inch was used, and the measures were made in either the third or fourth spectrum, the telescopes being set at an angle of 40°. The third spectrum was considerably the brighter, but experiment showed that the error of an observation expressed in wave-lengths was usually less in the fourth spectrum. With a wave-length of 5005 in the fourth spectrum, in the center of the field, one revolution of the micrometer = 2.21 tenth-metres, the dispersion being equal to that of about twenty-four prisms of 60°.

In the third spectrum, at the same place, one revolution = 3.71 tenth-metres.

With this dispersion, the brightest nebular line only was in the field. The lower of the two nitrogen lines and the edge of the magnesium fluting at λ 5006 were separated by a considerable interval, a small fraction of which could be measured by the micrometer. The nebular line was, of course, faint, but by narrowing the slit until the line was of the same width as the coarse micrometer wire (about 0.4 tenth-metres), the line could be occulted by the wire and the settings made with much accuracy.

The position of the nebular line was determined with reference to both the lower edge of the magnesium-flame band and the lead line at λ 5004.5 (adopting the wave-length given by Dr. HUGGINS), the two independent measurements serving as a mutual check. The lead line, however, furnished a much better mark for the micrometer. As an example, I give a summary of the measures in the spectrum of the nebula Σ 6. The telescope was usually directed to this nebula before beginning work on others, in order to verify the adjustment of the spectroscope. In the table, a positive sign means that the nebular line was of greater wave-length than the line of comparison; the negative sign, that it was of smaller wave-length.

Measures in the Spectrum of Σ 6.

DATE. 1890.	DISTANCE FROM LEAD LINE.		DISTANCE FROM MGO FLUTING.		OBSERVED WAVE-LENGTH.	CORRECTION FOR EARTH'S MOTION.	CORRECTED WAVE-LENGTH.
	Microm. Rev.	Tenth-metres.	Microm. Rev.	Tenth-metres.			
July 10	+0.64	+1.41	−0.18	−0.40	5005.94	−0.13	5005.81
" 17	+0.63	+1.39	−0.23	−0.51	5005.87	−0.17	5005.70
" 24	....	....	−0.12	−0.29	5006.07	−0.21	5005.86
" 25	....	....	−0.15	−0.33	5006.03	−0.21	5005.82
" 25	....	....	−0.13	−0.29	5006.07	−0.21	5005.86
" 31	+0.69	+1.52	−0.14	−0.31	5006.05	−0.25	5005.80
Aug. 1	....	....	−0.15	−0.33	5006.03	−0.26	5005.77
" 7	....	....	−0.13	−0.29	5006.07	−0.28	5005.79
" 8	....	....	−0.10	−0.22	5006.14	−0.29	5005.85

The adjustments of the apparatus were tested as often as possible by measures of the displacement of lines in the spectra of the moon and planets. In the case of the moon (and sun) the coincidence of lines by direct comparison was always perfect. Comparisons made by the aid of the micrometer wire, in the same way as in observing nebulæ, showed a displacement so small as to be usually within the accidental error of observation; thus, five measures of the position of the D_2 line in the lunar spectrum on the evening of July 31st gave a displacement of + 1 division of the micrometer, or 0.03 tenth-metres; five measures by another observer gave the same displacement, and five by still another observer a slightly greater negative displacement. On a number of days the displacement of the *D* lines was measured in the spectrum of *Venus*, the third spectrum of the grating being employed. Direct comparison showed a small displacement of the lines of the planet toward the violet, which was measured with the micrometer by alternate settings on the *D* lines and on the sodium lines produced by impurities in the magnesium points of the comparison apparatus, according to the method employed in the observations of nebulæ. The results are exhibited in tabular form below. One revolution of the micrometer for this position of the grating equals 3.29 tenth-metres, equivalent to a motion of 104.3 miles per second in the line of sight.

Measures of the Motion of Venus in the Line of Sight.

Date.	Observer.	Displacement of *D* lines.	Observed Motion.	Computed Motion.	C—O.
		r.	*miles.*	*miles.*	*miles.*
Aug. 16	K	-0.070	-7.3	-8.1	-0.8
" 22	K	-0.085	-8.9	-8.2	+0.7
" 22	C	-0.072	-7.5	-8.2	-0.7
" 30	K	-0.070	-7.3	-8.3	-1.0
Sept. 3	K	-0.0793	-8.3	-8.3	0.0
" 4	K	-0.079	-8.2	-8.3	-0.1

The smallness of the accidental errors of observation is shown in the above table by the agreement of the individual results, and the absence of constant errors by the agreement of the mean with the actual value of the quantity measured.

Occasional observations of nebulæ were made with a smaller

spectroscope, having a single 60° prism and ten-inch telescopes. This instrument gives brighter spectra than the large one with the same dispersion, but it has no micrometer or other measuring apparatus. It is referred to in the observations as spectroscope *B*.

I give, finally, the individual results for the nebulæ so far examined. The descriptive notes accompanying the record of observations on the appearance of nebulæ are my own, taken from my note-book used at the telescope. In general, they agree with the descriptions of others, although they contain some facts not hitherto published. Little attention was, however, paid to the ordinary visual observations, which were made either with the diagonal eye-piece of the large spectroscope, the slit being opened wide, to allow the object to be seen, or with an ordinary negative eye-piece on nights when the small spectroscope was used.

In the measures, the distance in tenth-metres of the nebular line from the lead line at λ 5004.5 is, for brevity, indicated by L, and its distance from the edge of the MgO fluting, just below, by M. The distance $M-L$ was found by several series of independent measures to be 1.86 tenth-metres. It was somewhat greater when the brilliant light from burning magnesium was used, as the illumination of the terminal line is not equal on both sides; but with the relatively feeble light of the comparison-spark used in the observations, the distance was that given above. Referred to the same scale as the lead line, the wave-length of the MgO fluting is therefore λ 5006.36.* As the distance $M-L$ is indirectly measured, through the nebular line, at each complete observation of a nebula, the agreement of the individual results with the value 1.86 tenth-metres gives a check on the accuracy of the observations. It may be noted that, in general, the observations of a nebula were made without any recollection of the results obtained on previous nights, and that the spectroscope was frequently dismounted during the period covered by the observations. Each complete determination of the position of a nebular line consists of five measures of its distance from the lead line and five from the magnesium fluting, the entire operation consuming more time than might be supposed by one unfamiliar with the difficulties of managing the necessarily complicated apparatus employed in such work.

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* The scale is ANGSTRÖM'S, known to require a correction of about one part in about eight thousand; but we are here concerned with relative positions only. Professor ROWLAND has kindly communicated to me the wave-length of the lead line from one of his photographs. It is 5005.6 $\pm$ 0.1.

Observations of Nebulæ.

(The places are for 1890.)

G. C. 4058. R. A. = $15^h\ 3^m\ 28^s$, $\delta = +56°\ 11'$.

This spindle-shaped nebula is divided lengthwise by a narrow, perfectly dark, straight rift, on each side of which, near the n. p. end, is a minute star of about the sixteenth magnitude. The continuous spectrum was examined for carbon bands with spectroscope *B*, but it was excessively faint, and no details could be seen. The light seemed to end rather abruptly at the lower end of the spectrum, in the orange. A short-focus telescope would be better for this object.

G. C. 4234. (Σ 5.) R. A. = $16^h\ 39^m\ 53^s$, $\delta = +24°\ 0'$.

This nebula was first examined on May 15. It is nearly round, and has a bright stellar nucleus, giving a continuous spectrum, in which a bright line at D_3 was suspected on one occasion. Outside of the nebula, but connected with it by a faint band of light, is a condensation of nebulosity, the spectrum of which is gaseous.

The following measures have been made:

Date.	L.	M.	Observed λ.	Reduc. to Sun.	λ.
June 13	....	-0.72	5005.64	-0.10	5005.54
" 27	....	-0.77	5005.59	-0.18	5005.41
" 27	....	-0.82	5005.54	-0.18	5005.36
July 3	+0.99	-0.75	5005.55	-0.20	5005.35
" 4	+1.02	....	5005.52	-0.21	5005.31
" 10	+1.02	....	5005.52	-0.24	5005.28

The second set of measures on June 27 was made in the third spectrum.

G. C. 5851. R. A. = $17^h\ 7^m\ 53^s$, $\delta = -12°\ 47'$.

The following measures were made in the third spectrum, and are all that have been obtained so far. The brightest line was very faint in the large spectroscope:

Date.	L.	M.	Observed λ.	Reduc. to Sun.	λ.
Aug. 15	+1.00	....	5005.50	-0.44	5005.06

G. C. 4355. R. A. = $17^h\ 55^m\ 43^s$, $\delta = -23° 2'$.

The spectrum of this (trifid) nebula is continuous, but short, being confined to the green and blue, and there is a brightening near the middle of it, the wave-length of which could not be estimated with spectroscope *B*. The brightest star involved gave a spectrum without lines, although if there had been dark lines as strong as they usually are in class I, they could probably have been seen.

G. C. 4361. R. A. = $17^h\ 56^m\ 56^s$, $\delta = -24° 23'$.

The lines were much too faint for observation with the large spectroscope. Examined with spectroscope *B* on August 21, three bright lines were seen, which were probably the usual nebular lines, although the two lowest seemed to be very close. The nebula is full of knots or condensations, having the same spectrum as its more diffuse portions, and many bright stars are involved in it, in the spectra of which no lines could be detected. This nebula is too diffuse for a long-focus telescope.

G. C. 4373. R. A = $17^h\ 58^m\ 35^s$, $\delta = +66° 38'$.

The appearance of this nebula in the thirty-six-inch equatorial has been described by Professor HOLDEN and Professor SCHAEBERLE.* The lowest nebular line falls higher in the spectrum than in any nebula yet examined, being nearly in coincidence with the lead line. Measures were obtained as follows:

DATE.	L.	M.	OBSERVED λ.	REDUC. TO SUN.	λ.
July 4	+0.29	-1.55	5004.80	0.00	5004.80
" 10	+0.29	-1.66	5004.75	0.00	5004.75
" 25	+0.55	-1.13	5005.14	0.00	5005.14
Aug. 15	+0.35	-1.55	5004.83	0.00	5004.83
" 22	+0.33	-1.55	5004.82	0.00	5004.82

The measures of July 25 were unsatisfactory, as a violent wind was shaking the telescope. They are, however, given with the others.

* *Mon. Not. R. A. S.*, vol. 48 (1888), p. 388.

On July 19 the spectrum of the nucleus was examined with spectroscope *B*, but nothing remarkable could be seen. Although there were indications of bright knots on the continuous spectrum below the group of lines in the green, they were not sufficiently distinct for a trustworthy estimate of their positions. VOGEL'S "*Spuren von Lichtlinien bei 527, 518, 509, 579*," were looked for, but were not visible, and D_3 could not be seen.

N. G. C. 6537. R. A. = $17^h\ 58^m\ 42^s$, $\delta = -19° 51'$.

The brightest line was too faint for observation with the large spectroscope.

G. C. 4390. (Σ 6.) R. A. = $18^h\ 6^m\ 45^s$, $\delta = +6° 50'$.

The measures of the position of the brightest line, have been given already. They make the wave-length of the line corrected for the motion of the earth, λ 5005.81.

This is one of the brightest nebulæ that I have examined. The third nebular line in the third spectrum was sufficiently bright for comparison with the $H\beta$ line of a hydrogen tube, although the measures were difficult, and the nebular line was found to be 0.86 tenth-metres (or, corrected for the motion of the earth, 0.60 tenth-metres) less refrangible. This evidently agrees (in direction, if not in amount) with the low position of the brightest line, shown by the measures already given.

Viewed with an ordinary eye-piece, the nucleus of Σ 6 does not appear perfectly sharp, but seems to blend into the surrounding nebula. An examination of its spectrum with spectroscope *B* confirmed this view as to the connection between the nebula and its nucleus, the continuous spectrum of the latter shading off somewhat gradually into that of the nebula, and showing a great increase in brilliancy where it was crossed by the nebular lines. Besides the usual lines 5005, 4957, $H\beta$ and $H\gamma$, several others were seen in the spectrum of the nucleus. D_3 was quite bright, and was identified by comparison with the sodium line from a spirit-lamp. $H\alpha$ was seen with great difficulty, at the extreme lower end of the spectrum. Other faint bright lines appeared at about 5680, 5400 and 4450, the positions being mere eye-estimates, and dark bands were suspected at two or three places between the brightest line and D_3. The principal lines were fine and sharp in the spectrum of the nebula, but fuzzy and considerably broadened in that of the nucleus. These observations are evidently in harmony

with the natural supposition that the nucleus is composed of condensed nebulous matter at a higher temperature and pressure.

G. C. 4447. R. A. = $18^h\ 49^m\ 30^s$, $\delta = +32^\circ\ 54'$.

The brightest line in the spectrum of the Ring nebula in *Lyra* was much too faint for measurement with the grating. No observations have been made with the small spectroscope.

N. G. C. 6790 (= D. M. + 1°.3979). R. A. = $19^h\ 17^m\ 20^s$, $\delta = +1^\circ\ 18'$.

This is one of the very small stellar planetary nebulæ discovered by Professor Pickering. It is rated in the D. M. as 9.4 mag.; is round, bright, and has a very minute nucleus, the general appearance of the nebula being much like that of Σ 6, on a smaller scale.

In this nebula the brightest line falls lower in the spectrum than in any nebula yet examined, being *less* refrangible than the edge of the magnesium fluting. This fact was seen at once from a direct comparison, and is also shown by the measures.

Date.	L.	M.	Observed λ.	Reduc. to Sun.	λ.
July 31	+2.30	+0.46	5006.81	−0.14	5006.67
Aug. 1	+2.45	+0.44	5006.88	−0.15	5006.73
" 8	+2.51	....	5007.01	−0.29	5006.72

G. C. 4510. R. A. = $19^h\ 37^m\ 46^s$, $\delta = -14^\circ\ 25'$.

The intrinsic brilliancy of this large nebula is small, and the measures were difficult. Those of August 8 were made in the third spectrum, and as the slit was wider than usual, the comparisons with the lead line are much more reliable than those with the magnesium fluting.

Date.	L.	M.	Observed λ.	Reduc. to Sun.	λ.
July 17	+1.33	−0.91	5005.64	−0.02	5005.62
Aug. 8	+1.37	−0.48	5005.87	−0.19	5005.68

G. C. 4514. R. A. = $19^h\ 41^m\ 51^s$, $\delta = +50^\circ\ 16'$.

The large, round, fairly bright disc of this nebula is apparently without structure. The nucleus is very bright, and was examined with

spectroscope B, in the expectation of finding a complicated bright-line spectrum. The spectrum was, however, continuous, and although bright points could be glimpsed in it, their positions could not be determined. In the large spectroscope the nebular lines were quite dim.

The following measures have been obtained:

DATE.	L.	M.	OBSERVED λ.	REDUC. TO SUN.	λ.
July 25	+1.54	−0.55	5005.92	−0.02	5005.90
Aug. 15	+1.39	−0.57	5005.84	0.00	5005.84

G. C. 4532. R. A. = $19^h\ 54^m\ 51^s$, $\delta = +22^\circ\ 25'$.

The lines of the Dumb-bell nebula were too faint for observation with a grating. No observations have been made with spectroscope B.

G. C. 4628. R. A. = $20^h\ 58^m\ 11^s$, $\delta = -11^\circ\ 48'$.

This is a large, round nebula, with a bright inner ring, considerably elongated E. and W., and a very small nucleus. The following measures were obtained with the large spectroscope. Those of July 31 were rather difficult, on account of the bright moonlight on the floor around the observer.

DATE.	L.	M.	OBSERVED λ.	REDUC. TO SUN.	λ.
July 31	+0.66	−1.13	5005.20	+0.04	5005.24
Aug. 22	+0.71	−0.88	5005.35	−0.13	5005.20

N. G. C. 7027 (=D. M. $+41^\circ.4004$). R. A. = $21^h\ 2^m\ 55^s$, $\delta = +41^\circ\ 48'$.

This is the brightest nebula that I have yet examined, and its spectrum is exceedingly interesting. The nebula is irregular in outline, and contains two central condensations, one of which has an oval and fairly well-defined outline. The other is much fainter and more diffuse. On the following side is a small star, just at the border of the nebula. The spectrum was examined on August 21 with spectroscope B. The lowest line is *brilliant*, the second also very bright, but the hydrogen lines are relatively dim, and an attempt to compare the third line with $H\beta$, with the large spectroscope, failed. By widening the slit, a monochromatic image of the central conden-

sation could be seen in the brightest line, which became a mere knot or brightening on the line when the slit was narrowed. The continuous spectrum of the nebula showed but a comparatively slight brightening at the nucleus, which is evidently in a much less condensed state than the nuclei of Σ 6 and many other nebulæ of its kind. Several bright lines below the strong group in the blue were visible only in the spectrum of the central condensation, probably on account of their faintness. One of these, the lowest visible, was in the estimated position of D_3; another, very well seen, was at about λ 5400, and between this and the brightest line were several others, of which the only one that could be definitely fixed was at about λ 5200. It should be remembered that these positions are from mere eye-estimates, using the intervals between known lines as terms of comparison. This nebula also shows the line at λ 4700$\pm$, which is visible in the spectrum of *G. C. 4964*.

With the large spectroscope, measures of the position of the brightest line were obtained, as follows:

DATE.	L.	M.	OBSERVED λ.	REDUC. TO SUN.	λ.
Aug. 15	+1.57	-0.35	5006.04	+0.07	5006.11
" 22	+1.55	-0.20	5006.11	+0.03	5006.14

G. C. 4964. R. A. = $23^h\ 30^m\ 27^s$, $\delta = +41°\ 56'$.

This nebula is annular, with a bright inner ring and a very small nucleus. It is somewhat elongated N. and S.

The spectrum shows, in addition to the two brightest nebular lines and the hydrogen lines $H\beta$ and $H\gamma$, a line at about λ 4700, which was seen by HUGGINS in his first spectroscopic observations of nebulæ, in 1864. Examined with spectroscope *B*, on August 21, no other lines than the above were seen. The lines showed bright knots where the inner ring of the nebula was crossed by the slit. The spectrum of the nucleus was excessively faint, but there was a broad, faint, continuous spectrum, due to the nebula itself.

The following are measures with the large spectroscope:

DATE.	L.	M.	OBSERVED λ.	REDUC. TO SUN.	λ.
Aug. 1	+1.19	-0.95	5005.50	+0.32	5005.82
" 7	+0.80	-1.04	5005.31	+0.30	5005.61

In seeking to determine the motions of the nebulæ from these observations a difficulty presents itself which does not occur in observations of the motions of stars in the line of sight. The origin of the brightest nebular line is unknown, and hence we have no terrestrial substance with which to make a direct comparison. If, however, we had a large number of determinations of the position of the nebular line, from observations of nebulæ distributed with some uniformity throughout the sky, we could regard the mean position as that due to a nebula without motion, and the residuals obtained by comparing the individual results with the mean would represent the corresponding displacement of the line for each nebula. This has been done with the observations so far obtained; but as the nebulæ observed are far from having the regular distribution which is desirable, and are few in number, the numerical results are not to be regarded as final. Observations of other nebulæ will be made here until a sufficient number shall have been obtained.

Motions of Planetary Nebulæ in the Line of Sight.

(A positive sign signifies recession; a negative sign, approach.)

Nebula.	λ.	Displacement.	Motion per Second.
	tenth-metres.	*tenth-metres.*	*miles.*
G. C. 4234 (Σ 5)	5005.38	− 0.30	− 11.2
G. C. 5851	5005.50	− 0.18	− 6.7
G. C. 4373	5004.85	− 0.83	− 31.0
G. C. 4390 (Σ 6)	5005.81	+ 0.13	+ 4.8
N. G. C. 6790	5006.71	+ 1.03	+ 38.4
G. C. 4510	5005.65	− 0.03	− 1.1
G. C. 4514	5005.87	+ 0.19	+ 7.1
G. C. 4628	5005.22	− 0.46	− 17.2
N. G. C. 7027	5006.13	+ 0.45	+ 16.8
G. C. 4964	5005.72	+ 0.04	+ 1.5
Mean............	5005.68		

It is probable that a greater number of nebulæ would give a somewhat smaller mean wave-length for the position of the brightest line, and that therefore the motions of approach in the above table are too large, and those of recession too small. The single comparison

of the third line in the spectrum of Σ 6 with the hydrogen line $H\beta$ also indicates a higher mean position of the nebular line, although the observation was subject to rather large accidental errors. The *difference* of motion of the nebulæ given in the table I believe to have a considerable degree of accuracy,—*i. e.*, that the errors do not much exceed two or three English miles.

The spectra of the nuclei of planetary nebulæ have a remarkable resemblance to the spectra of the WOLF-RAYET and other bright-line stars, and intimate connection between these objects, if established by further observations, would place the bright-line stars first in the order of development. The D_3 line appears in the central condensation of a number of bright nebulæ, and, with sufficient light, would probably be seen in many of them, and this line is also prominent in most of the bright-line stars. Other lines in the nebulæ and stars are probably of identical origin. At my request, Mr. BURNHAM and Mr. BARNARD examined the WOLF-RAYET stars in *Cygnus* for traces of surrounding nebulosity, but with only negative results.

In making the observations described in this paper I was very kindly assisted by Mr. W. W. CAMPBELL, of the Detroit Observatory, University of Michigan, and Mr. A. O. LEUSCHNER, of the University of California, and these gentlemen also verified many of the observations. Without their aid, the work would have been much more laborious, and the results more incomplete.

LICK OBSERVATORY, September 4, 1890.

NOTE.—Since the above was printed, I have seen No. 293 of the *Proceedings of the Royal Society*, in which Mr. LOCKYER describes his recent observations, and arrives at conclusions which cannot be reconciled with my own. There is, however, nothing that I could wish to change in my paper, since it is simply a record of observed facts. In only one place (observations of Σ 6) have I referred the observed appearances to a cosmical theory, and the reader can easily supply any other explanation that is in accordance with the facts.

The errors which Mr. LOCKYER mentions as liable to arise from imperfect adjustment of the collimator axis and from parallax, seem to me excessive, if the telescopes are good and the adjustments are carefully made, and if they existed they would make observations of motion in the line of sight impossible. Certainly no errors approaching them in magnitude were produced in my own apparatus, when, in testing for constant errors, the various adjustments were purposely disturbed by amounts greater than could occur in practice. Among the many ex-

periments which were made was the one suggested by Mr. LOCKYER—rotating the spectroscope 180° between measures, but no appreciable effect was produced upon the position of the nebular line.

As regards accuracy of positions, there is a great advantage in using a very high dispersion, such as was employed in these measures, since any angular displacement of the parts of the apparatus produces but a small error measured in wave-lengths. The measures are also *differential*, the reference line being in the same field and the telescope fixed in position. They are affected by any error in the assumed place of the reference line, but this is immaterial for the purposes of the investigation.

On referring to my measures, it will be seen that they apparently have a vastly higher degree of accuracy than that which Mr. LOCKYER considers attainable. When it is remembered that these measures were made on different nights (the spectroscope usually having been dismounted in the interval), and frequently without any recollection of the results previously obtained, it appears in the highest degree improbable that the agreement of the different results for the same object should be the result of accident. In the observations of the motion of *Venus* in the line of sight, the interval between the *D* lines appeared under an angle of 1° 17′, as viewed with the eye-piece, and any good observer, on noting the small displacement of the lines of the planet, would admit the possibility of measuring this displacement to within a tenth part of its value. Hence, the accuracy of the measures in this case cannot be regarded as accidental, and for the nebulæ, on which even a higher dispersion was employed, the probable error of a setting was not much greater.

In regard to the *character* of the chief nebular line, I can only repeat that I see no tendency in it to assume the fluted appearance described by Mr. LOCKYER, either in the nebula of *Orion* or in the others I have observed, some of which are fainter and some very much brighter. Near the nucleus of a nebula, if it has one, the lines become broader and hazy, but equally so on both sides, and, as nearly as their different degrees of brightness will allow one to judge, all the lines are affected alike.

For faint, extended nebulæ, the great focal length of the thirty-six-inch equatorial is a positive disadvantage, and I do not attach much weight to the negative results obtained in the examination of some of these objects giving continuous spectra.

J. E. K.